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Influence Of Wind Turbines On Mammalian Occupancy Patterns

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INFLUENCE OF WIND TURBINES ON MAMMALIAN OCCUPANCY PATTERNS

being

A Thesis Presented to the Graduate Faculty
of the Fort Hays State University in
Partial Fulfillment of the Requirements for
the Degree of Master of Science

by

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This Thesis for

The Master of Science Degree

By

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PREFACE

This thesis is written in the style of the Journal of Mammalogy, to which a portion will be submitted for publication.

ABSTRACT

Wind energy is among the most rapidly growing energy industries in the United States, with support for development coming from both state and federal governments. While the industry depicts an environmentally friendly image, the addition of infrastructure associated with wind farms alters landscapes in novel ways. Numerous studies have documented impacts wind turbines have on bird and bat mortality; however, far less attention has been directed towards responses of non-volant, terrestrial organisms. Mammalian mesocarnivores are model organisms to assess the alteration of communities surrounding wind turbines as they respond to addition of turbines and human activity, addition and improvement of roadways, and increases in turbine-induced carrion. In September 2011, I established a yearlong study surrounding the Central Plains Wind Facility in western Kansas to document patterns associated with the occupancy of terrestrial mammals within turbine and turbine-free habitats. I placed 34 scent-baited trail cameras among turbine and control habitats, with a randomly placed subset along roadways. Detection histories during 28-day survey periods and habitat covariates were analyzed with PRESENCE 5.5. *Canis latrans* and *Vulpes velox* were the most abundant mesocarnivores detected. *Canis latrans* had a higher probability of occupancy at the control area, while *V. velox* had higher probabilities of occupancy at the turbine area. Detection probabilities were impacted strongly by mean precipitation as well as between field and roadway locations for *V. velox*. *Vulpes velox* detection probabilities were conditional on *C. latrans* presence and detection, although the two species occupied sites independently.

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INTRODUCTION

During the past decade, wind energy has been among the fastest growing energy industries within the United States (American Wind Energy Association Data Services 2012; Pasqualetti et al. 2004). This growth was spurred by federal and state incentive programs as part of the US Department of Energy's (DOE) plan to have 20% of the nation's energy derived from wind by the year 2030, roughly equaling 300 gigawatts (Lindenberg 2008; Menz and Vachon 2006). Despite record growth, the amount of electricity generated from wind by 2012 was only 60 gigawatts (American Wind Energy Association Data Services 2012). Ideal locations to construct the large scale wind facilities necessary to reach the DOE's goals, where consistent wind at 80 m exceeds 6.5 m/s, have been identified along the Appalachian, Serra Nevada, and Cascade mountain ranges as well as over the majority of the Great Plains (Kuvlesky et al. 2007; Lindenberg 2008; Nazzaro 2005). These areas of high wind potential also are along migration routes of many species of birds and bats, leading to increased stakeholder awareness of negative turbine-wildlife interactions (Arnett et al. 2008; Arnold and Kennedy 2008; Erickson et al. 2001; Kuvlesky et al. 2007; Nazzaro 2005).

Birds and bats have been the focus of most studies examining turbine-wildlife interactions (Kuvlesky et al. 2007). Avian collisions with turbines have been documented since the beginning of commercial wind energy production in the United States during the 1980s (Erickson et al. 2001). Historically, studies focused on raptor mortalities in California; however, modern turbines have design alterations that have drastically reduced avian mortality, including longer and slower moving blades (Erickson et al. 2001; Kuvlesky et al. 2007). Bird mortalities from turbines are currently estimated to be 2.19 birds/turbine/year with approximately 0.033 raptor fatalities/turbine/year (Erickson et al. 2001; Kuvlesky et al. 2007). Although these mortality rates are an order of magnitude lower than other causes of collision-based bird mortality, such as fence-lines, windows and vehicles, the location of wind facilities typically coincides with migration routes and impacts species of special concern (Arnold and Kennedy 2008; Erickson et al. 2001; Kuvlesky et al. 2007). Another issue with turbines and bird populations are impacts on habitat degradation for grassland nesting birds (Kuvlesky et al. 2007; Robel 2002). Some species of grouse, including the lesser prairie-chicken (*Tympanuchus pallidicinctus*), are threatened at state levels. As these species' habitat is often ideal for wind development, there are concerns that turbines will disrupt breeding and recruitment, increase collision mortalities and predation events, and further range contractions (Arnold and Kennedy 2008; Robel 2002; Wolfe et al. 2007).

Bat mortalities from turbines were known worldwide; yet not thought to occur with significant frequency until reports from the Mountaineer Wind Energy Center in West Virginia estimated 1,400-4,000 bat mortalities in 2003 (Arnett et al. 2008; Ellison 2012; Kerns and Kerlinger 2004). Since that time, numerous studies have documented high mortality rates for bats, with estimated national mortality rates of 28.5 bats/turbine/year (Arnett et al. 2008; Ellison 2012; Kuvelsky et al. 2007). These rates are substantially higher than bird mortalities as bats need not be directly struck by the turbine blade to die, rather bats can succumb to barotruama, the damage to tissues from high pressure gradients between inside and outside of the body, caused by turbine blade movement (Baerwald et al. 2008). Furthermore, there is evidence that certain bats, primarily juvenile male, migratory, tree-roosting bats such as those in the genus *Lasiurus*, are attracted to the turbines and thus killed more frequently (Arnett et al. 2008; Ellison 2012). Bat mortality estimates, as well as bird mortality estimates, vary regionally and are based on relatively few published studies. Mortality rates are estimated from carcass searches around wind turbines, which are lower than actual mortality rates due to variable searcher efficiency and carcass removal by scavengers (Arnett et al. 2008; Ellison 2012; Kuvlesky et al. 2007; Smallwood 2007). While these issues are ever present, estimated mortality rates are accepted as accurate and research is focusing on minimizing future impacts through siting and operational changes (Arnett et al. 2011; Ellison 2012).

While bird and bat turbine-related impacts are essential for the industry and management agencies to address, there are other wind-wildlife interactions that are neglected, including the scavenging mammal community (Helldin et al. 2012; Kuvlesky et al. 2007). Scavenging behavior often occurs at relatively high frequencies. However, scavenging as a process has been historically neglected by ecological studies, despite impacting community structure (DeVault et al. 2003; Selva and Fortuna 2007). Studies assessing scavenging rates on experimentally placed carcasses in turbine free habitats have reported carcass removal rates ranging from 13-100% (Antworth et al. 2005; DeVault et al. 2003; Wolfe et al. 2007). The prevalence of scavenging near turbines and the potential for impacting community structure and energy flow demonstrates the need for understanding scavenger guild around wind farms. While the National Wind Coordinating Collaborative Wildlife Group has stressed the importance of monitoring scavenging mesocarnivores for more accurate assessments of mortality, only a few studies have examined the rates at which scavenging occurs within wind farms, and no published studies have monitored mesocarnivore population dynamics (Arnold and Kennedy 2008; Helldin et al. 2010; Kuvlesky et al. 2007; Smallwood 2007; Smallwood et al. 2010). Although, monitoring mesocarnivore populations might improve scavenging estimates, another goal for studying mammalian mesocarnivores is to improve our understanding of how mesocarnivores are distributed around wind turbines, as this will help show the ecological effects wind farms have on the entire community.

Mammalian mesocarnivores have a pronounced impact upon the entire community as they affect population levels of a diverse range of prey species and affect energy flow throughout a landscape (DeVault et al. 2003). Furthermore, the habitat fragmentation associated with wind energy facilities would be expected to have a pronounced impact upon mammalian mesocarnivores, making them model study organisms. Wind facilities require extensive infrastructure to remain operational (Helldin et al. 2012; Kuvlesky et al. 2007). In addition to the 80 m tall turbines and base pads, an extensive network of above and below ground electrical cables are needed (Helldin et al. 2012). Roadways are added or improved to handle construction and maintenance, which increases edge habitat and movement corridors for mesocarnivores (Forman and Alexander 1998; Helldin et al. 2012; Kuvlesky et al. 2007). This has led to predictions of increased activity and predation events by mesocarnivores around turbines and also higher mesocarnivore gene flow in the surrounding community (Helldin et al. 2012; Robel 2002). Wind facilities also add maintenance buildings and change the level of human activity in the area, which could further alter activity patterns of mesocarnivores (Helldin et al. 2012; Kuvlesky et al. 2007). Finally, the predicted increase of carrion into the area, due to turbine related mortality, increases the food resources available to mesocarnivores. As mortality events are temporally predictable, mesocarnivores might detect these events and modify their behavior to take advantage of this ephemeral resource (Arnett et al. 2008; Antworth et al. 2005; Crawford 1971; DeVault et al. 2003; Selva and Fortuna 2007).

One difficulty with studying the activity patterns of mesocarnivores is their elusive nature. However, this can be overcome through the use of occupancy modeling. Occupancy modeling accounts for imperfect detections in presence-absence data to infer the probability a species occupies an area but is not detected (MacKenzie et al. 2006). This maximum likelihood analysis allows for inference in systems where species are difficult to observe or trap, are found in a large area, or investigators have limited resources. Questions of occupancy, the probability that a site is occupied by a target species for some amount of time, when analyzed with covariates can test hypotheses regarding geographic range, habitat use, resource selection, population dynamics, species interactions, and other pressing ecological inquiries (MacKenzie et al. 2006; O'Connell and Bailey 2011).

In an effort to address the impacts that wind turbines have on the ecosystem, my study explored the occupancy dynamics of the mammalian mesocarnivore community at a wind energy facility. My objectives were to document which mesocarnivore species occupy wind energy facilities and at what frequencies they are detected, determine what factors are driving patterns of occupancy, and analyze if wind turbines are impacting the occupancy dynamics of mesocarnivores compared to non-turbine habitats.

MATERIALS AND METHODS

Study sites - The study area, located along the eastern border of Wichita County, Kansas, was divided into a turbine area and a control area. The turbine area consisted of the Central Plains Wind Farm, approximately 2.5 km northwest of Marienthal, KS. The 2,400 ha wind facility is owned and operated by Westar Energy. The facility, comprising 33 Vestas V90 turbines generating 99 MW/year, has been operational since 2009. The control area was located ≥ 8 km southwest of the wind farm to establish independence between the turbine and control areas. State highway 96 also separated the turbine and control areas, increasing independence (Fig. 1). The control area was selected for similarity to the turbine area based on topography and microclimate. Both areas were dominated by agriculture mixed with minimal amounts of Conservation Reserve Program (CRP) grasslands. Agricultural fields were split between irrigated and dry-land practices. Crop types depended on season and rotation by the farmers yet consisted of, in order of frequency, winter wheat (*Triticum aestivum*), milo (*Sorghum sp.*), and maize (*Zea mays*).

Each study area was divided into 250 x 250 m grids on either side of roadways, representing distinct survey sites. Sites for surveys were established at this distance to maximize detections while maintaining independence based on camera survey literature (Larrueca et al. 2007; Long and Zielinski 2008; MacKenzie et al. 2006; Sequin et al. 2003). The control area had 24 sites while the turbine area had 30 sites. Sixteen sites were chosen in a stratified random design within each study area. Of these, half were designated with roadway locations and half designated field locations. One Stealth Cam Unit 840 Passive Infrared trail camera was placed within the center of each site, either along the roadway or field edge of the grid according to prior designation. Placement of the camera avoided direct sunlight on the lens and, whenever possible, was placed in an area of minimal vegetation to minimize false triggers of the cameras (Kays and Slauson 2008; Swann et al. 2011). Each camera was attached to a 1 tall m metal fencepost with plastic cable ties and fixed with a surveyor's flag. Posts were placed so the camera was 0.5 m off the ground. Cameras were baited with approximately 5 ml of homemade rotten bird egg material placed in plastic centrifuge vials. The vials were pressed fully into the ground between 1 and 2 m from the camera and the vial caps were loosened. This was done to increase detections of mesocarnivores while not offering them a reward (Schlexer 2008; Swann et al. 2011). Cameras were set to record 3 pictures per trigger event, with a delay period of 1 sec between trigger events. Each camera was equipped with an 8 gigabyte memory card and was able to take approximately 9,500, 3.5 megapixel photographs.

Cameras were left for 28-day survey periods to maximize detections of elusive mesocarnivores and eliminate moon phase bias (Long and Zielinski 2008; MacKenzie et al. 2006). A modified double-sampling design was implemented where at the end of each survey period, the cameras and scent lures were relocated, with new lures and memory cards, into a randomized grid site and location. This increased the coverage of sampling units, while still allowing for repeat surveys with the added benefit of minimizing negative interactions with agricultural activities such as harvesting and disking (Long and Zielinski 2008; MacKenzie et al. 2006). Cameras were relocated by using prior stratified random designations. However, at the judgment of field technicians, when placement was thought to interfere with agricultural activities, a new site was assigned. New sites also were assigned in the field when vegetation at sites would obstruct camera operation (e.g., the height of maize stalks exceeding the lens). Sampling took place from 24 September 2011 through 20 October 2012 during which there were 14 survey periods.

Detection histories - All 432,831 images taken during the study were analyzed and labeled with metadata with ExifPro Photo Browser (Kowalski and Kowalski 2011). Mammalian species detected were identified to species when possible. Detection histories were compiled for each species according to site. Sites that had camera failure, the premature cease of triggering detections due to physical or technical error prior to 14 survey days, or did not have a camera present were coded as missing data.

Covariate sampling – I created an a priori list of climate, land cover, and human use covariates that might influence mesocarnivore detection and occupancy probabilities. Climate data, including mean temperature, precipitation, and snow cover, were obtained for each survey period from the National Climatic Data Center daily records from the nearest station, (Scott City, KS, USA; GHCND:USC00147271) located 21 km east of the study areas. Land cover data included land use, CRP versus agricultural, and crop type, which were compiled from ground truthing at the beginning and end of each survey period. Camera site locations were classified as either field or roadway locations. Distance from camera to nearest building was measured using GPS locations of cameras and 2012 satellite imagery. A human activity index was calculated by using the mean amount of vehicles and pedestrians detected with trail cameras at each study area over time.

Occupancy modeling – The detection histories for each species were entered into program PRESENCE version 5.5 along with covariate data for occupancy modeling (Hines 2006). Multiple seasons (Table 1) were defined according to biological significance to mesocarnivores and the lunar cycle, including: 1) pack coalescence from September to November, 2) reproduction from November to March, 3) dispersal from March to July, and 4) summer from July to August (Bekoff 1977; Egoscue 1979). Wind facility manipulation (turbine area versus control area) and land use (agriculture versus CRP) were included as site covariates, variables impacting detection and occupancy probabilities that remain unchanged for sites from survey period to survey period. Site location (roadway versus field), camera distance to nearest building, human activity index, and weather data were used as sampling covariates, variables impacting detection and occupancy probabilities that change for sites from survey period to survey period. Models were run for each mesocarnivore species with more than 20 modelable detections, which I define as the first detection of a species at a site during the survey period. A multi-step approach was used to determine which candidate models to use for seasonal effects and the highest supported detection covariates (MacKenzie et al. 2006). Seasonal patterns were modeled first with the top model being selected for use with the full set of covariates through single species, multi-season models. Model support was assessed by using Akaike's Information Criterion (AIC) and 95% confidence intervals. Probability of occupancy and detection were calculated in addition to the influence of covariates using a logit-link function. Multi-season, conditional two-species co-occurrence models were run, by using the psiBa parameterization method, between *Canis* *latrans* and *Vulpes velox* with only the highest supported detection covariates from previous models in an effort to reduce the candidate model set to 33 models (Richmond et al. 2010). These models tested the effect of *C. latrans* presence and detection on *V. velox* detection probability, *C. latrans* presence on *V. velox* occupancy, and the how the occupancy for both species was impacted by turbines. *Canis latrans* was presumed to be the dominant species of canid based on other studies in this region (Jackson and Choate 2000; Matlack et al. 2000). Colonization and extinction probabilities were held constant and seasonal detection probability covariates were removed due to lack of power. Dominance was assessed by examining the AIC weight of models and model categories (e.g., conditional versus unconditional). I also calculated a species interaction factor (SIF) as a function of the top 5 model averaged occupancy estimates for both species (Richmond et al. 2010).

Statistical analysis

Detection history assessment - A chi-square test of independence with Yate's correction was used for each species to determine if modelable detections occurred more frequently in the control or turbine areas. I used a Welsh's two sample t-test to assess modelable detections of mesocarnivores at each study area over time. I also reported the frequency of mesocarnivores over the course of a 24 hour period.

Independence of variables - To analyze for autocorrelation in modelable species detections I ran a Mantel test of matrix correspondence with day of modelable detection and GPS location of the cameras for each species run with occupancy modeling. Euclidean distances were used for both parameters. Covariates were tested prior to use in modeling to help determine biological significance. A Student's *t*-test was used to show significant differences between survey periods for mean temperature, precipitation, and snow cover. I used a Welsh's two sample *t*-test to assess similarity of the distance from camera to nearest building and the human activity index across study areas.

RESULTS

Detection history assessment - I had 276 detections of 7 species of mammalian mesocarnivores during the 9,291 camera-days of the study. Detected mesocarnivore species included: *Canis latrans* (n=126), *Vulpes velox* (n=106), *Mephitis mephitis* (n=25), *Procyon lotor* (n=10), *Taxidea taxus* (n=6), *Mustela frenata* (n=2), and *Felis domesticus* (n=1) (Table 2). Due to power constraints, only species with more than 20 modelable detections, *C. latrans* (n = 64) and *V. velox* (n = 51), were modeled. Mesocarnivores as a guild were detected equally at both turbine and control habitats ($\chi^2 = 0.33$, *d.f.* = 1, $P = 0.05$). *Canis latrans* was detected significantly more frequently in the control area ($\chi^2 = 5.64$, *d.f.* = 1, $P = 0.05$), while *V. velox* was detected significantly more frequently in the turbine area ($\chi^2 = 15.37$, *d.f.* = 1, $P = 0.05$). There was no significant difference in mesocarnivore detections between study areas over the course of the study period ($t = 0.65$, *d.f.* = 25.1, $P = 0.52$) (Fig. 2). The frequency of detections of *C. latrans* and *V. velox* over the span of 24 hours indicated crepuscular activity for both species (Fig. 3).

Independence of variables - The Mantel test showed low levels of autocorrelation among *C. latrans* ($r = 0.062$, *d.f.* = 54, $P = 0.04$) and no significant autocorrelation for *V. velox* ($r = -0.025$, *d.f.* = 43, $P = 0.70$) (Fig. 4). Mean temperature ($t = 4.94$, *d.f.* = 13, $P < 0.001$) and precipitation ($t = 3.31$, *d.f.* = 13, $P = 0.006$) showed significant differences across survey periods and were used as covariates for modeling, while mean snow cover did not significantly differ between survey periods ($t = 1.16$, *d.f.* = 13, $P = 0.27$) and was deemed not biologically relevant for modeling. Distance to nearest building was significantly different between control and turbine areas with buildings being closer to cameras at the turbine area ($t = 3.23$, *d.f.* = 186.5, $P = 0.001$). Human activity differed significantly between study areas ($t = 5.72$, *d.f.* = 131.9, $P < 0.001$) with more activity detected at the control area (Fig. 5).

Occupancy modeling

Canis latrans models – The top seasonal occupancy model for *C. latrans,* compared to the full set of candidate models (Table 3), had constant seasonal colonization and detections ($w = 0.86$, $K = 3$, $-2*\log(L) = 239.72$). The 15 single species, multi-season models (Table 4) showed a top model with seasonal occupancy as a function of the control area, colonization did not differ, and the probability of detection varied as a function of mean precipitation ($w = 0.20$, $K = 3$, $-2*\log(L) = 239.72$). Estimates for the probability of occupancy ($\beta = 1.47 \pm 0.89$) and probability of detection ($\beta = -1.95 \pm 1.07$) and their respective covariates both showed no significant predictive power. Probability of detection as a function of mean precipitation and distance to nearest building also were included in the model with the second most support ($w = 0.15$, $K = 4$, $-2*\log(L) = 229.63$). For further clarity, tables 3 and 4 are reproduced in appendix I without phidot notation (Tables I3 and I4).

Vulpes velox models – The highest supported seasonal occupancy models for *V. velox* (Table 5), allowed occupancy and detections to vary with season while colonization did not vary ($w = 0.49$, $K = 8$, $-2*\log(L) = 213.40$). Of the 26 single species, multi-season models (Table 6), the top model had occupancy varying with season, differing between the turbine and control areas, colonization constant, and detection probabilities varying as a function of seasons, field location, and mean precipitation ($w = 0.12$, $K = 11$,

-2*log(*L*) = 182.47). The differences in occupancy among turbine and control areas were significant (β = -21.37 ± 0.00). Probability of detection increased over the course of the study (0.18, 0.18, 0.14, 0.59, 0.45); however, these coefficients were associated with high standard errors (± 37.2) and thus did not have significant explanatory power. This pattern of increased detection probabilities was likely the result of increased detections over time (Fig. 2). Probability of detection significantly varied between field and roadway locations (β = -1.87 ± 0.48). Mean precipitation did not significantly affect detection probability (β = 1.55 ± 0.95). Probability of detection showed moderate support as the second ranked model, varying with seasons and between field and roadway locations (*w* = 0.09, *K* = 10, -2*log(*L*) = 185.10). The third ranked model, in which probability of detection varied by season, between field and roadway locations, and agricultural and CRP land use, also showed moderate support (*w* = 0.09, *K* = 12, -2*log(*L*) = 181.20). For further clarity, tables 5 and 6 are reproduced in appendix I without phidot notation (Tables I5 and I6).

Species co-occurrence models – The full candidate set contained 33 species co-occurrence models (Table 7). For further clarity, tables 7 is reproduced in appendix I without phidot notation (Table I7). *Vulpes velox* detection probability was influenced strongly by the presence and detection of *C. latrans* with a cumulative Akaike weight of 0.99 (Table 8). Also, *V. velox* occupancy was conditional on *C. latrans* occupancy with a cumulative Akaike weight of 0.94 (Table 8). The top model had *C. latrans* occupancy uninfluenced by control and turbine areas, but *V. velox* detections varied at the control and turbine areas when *C. latrans* was present and uninfluenced by control and turbine areas when *C. latrans* was not present ($w = 0.64$, $K = 17$, $-2*\log(L) = 412.97$). Occupancy covariates for this model suggested when *C. latrans* was present in the control area, the probability of occupancy for *V. velox* was 1.00 (1.00,1.00) and when *C. latrans* was present in the turbine area the probability of occupancy for *V. velox* was 0.00 (0.00, 0.00). Despite this strong relationship, the top model was describing a very small, albeit interesting, portion of the overall data. Therefore, I used the second ranked model (ΔAIC = 3.74) for majority of the insights about the study system.

The second model (Table 7) had *C. latrans* probability of occupancy varying between the control and turbine areas. *Vulpes velox* probability of occupancy when *C. latrans* was present varied between the control and turbine areas and when *C. latrans* was not present the probability of *V. velox* occupancy did not vary between the control and turbine areas ($w = 0.09$, $K = 18$, $-2*\log(L) = 414.71$). *Canis latrans* had a probability of occupancy of approximately 1.00 (1.00,1.00) at the control area. When *C. latrans* was absent, *V. velox* had a probability of occupancy at the turbine area of approximately 1 (1.00, 1.00). Both of these relationships were considered to have predictive explanatory power. The naïve estimates for colonization and extinction across all sites was -0.55 (± 0.45) and -44.01 (± 10.00) respectively. The probability of detecting *C. latrans* was a nonsignificant function of mean precipitation, (Fig. 6) with naïve estimates of -1.58 (± 0.94). The probability of detection for *V. velox* when *C. latrans* was absent, was a function of mean precipitation ($\beta = 1.10 \pm 1.78$) and field locations ($\beta = -0.86 \pm 0.99$), although both were not deemed significant. The probabilities of detecting *V. velox* when *C. latrans* was present but either detected or undetected were significantly predictive functions of both mean precipitation and field versus roadway locations, and showed levels of species interaction. When considering *V. velox* probability of detection as influenced by mean precipitation, there was a pronounced change from a positive association with precipitation when *C. latrans* was detected, to a negative association when *C. latrans* was not detected (Fig. 7). When considering field locations as a function of detection probabilities, *V. velox* was more likely to be detected at only roadway locations when *C. latrans* was present and detected (p = 0.99) versus present but undetected (p = 0.81; Fig. 8). The cumulative AIC weight of the top five models was 0.92.

DISCUSSION

Though mesocarnivores as a guild were detected evenly between turbine and control areas, *Canis latrans* and *Vulpes velox* detections were significantly different between both areas (Table 2). Over the duration of the study, mesocarnivore detections per survey period increased slightly in both the turbine and control areas. This insignificant rise is expected to be from random population fluctuations and not from acclimation to turbines or cameras. While no significant differences were seen between sites, one notable exception is during March and April when detections at the control site suddenly peaked (Fig. 2). The increase in detections consisted primarily of *Canis latrans* and represented the dispersal period for juveniles (Bekoff 1977; Larrueca et al. 2007). The lack of significant changes in detections over the course of the study period was counter to previously stated hypotheses that an influx of bird and bat mortality during migration periods would lead to increased detections of mesocarnivores. I cannot determine from this study whether this pattern is due to a lack of mesocarnivore reaction to mortality events or if there are minimal fluctuations in mortality events at this wind facility. However, there is ample evidence that mesocarnivores modify behaviors to predictable mass mortalities, (Antworth et al. 2005; Crawford 1971; DeVault et al. 2003; Selva and Fortuna 2007), which suggests there are few fluctuations in turbine-related mortalities at the Central Plains Wind Facility. Low numbers of mortality events could be attributed to the siting of the wind farm away from large water bodies and woody areas, and on the outskirts of the Central Migratory Flyway (Arnett et al. 2008; Kuvlesky et al. 2007; Nazzaro 2005).

Contrary to expectation (Helldin et al. 2012; Kuvlesky et al. 2007), less human activity was observed at the turbine area than the control area (Fig. 5). While there were many maintenance vehicles at the turbine site, many of the roads were gated to limit use. Human activity did not influence the detection or occupancy of *C. latrans* or *V. velox*. Many mesocarnivore species avoid human activity in rural areas (Bekoff 1977; Forman and Alexander 1998; Helldin et al. 2012; Larrueca et al. 2007; Sequin et al. 2003). However, *C. latrans* was detected in areas of increased human activity, suggesting the differences between control and turbine areas was strong enough to modify typical behaviors. The frequency of detections over the span of 24 hours provided some evidence that *C. latrans* was impacted differently by the human activity at the turbine area than at the control area. *Canis latrans* detections at the control site extended much further into the daytime hours, while at the turbine site detections dropped to 0 during the course of the typical workday (Fig. 3).

Mean precipitation influenced the probability of detecting both *C. latrans* and *V. velox*, with both species being less likely to be detected with precipitation. This is counter to original expectations as bird and bat mortalities have been shown to increase immediately prior to precipitation events (Arnett et al. 2008). This again suggests the Central Plains Wind Facility has a low number of mortality events. Precipitation increases olfactory detection by mesocarnivores and rainfall events often increase rodent activity (Gentry et al. 1966; Vickery and Bider 1981), suggesting scent-based mesocarnivores would have greater foraging success during precipitation. Mesocarnivores are expected to forage optimally so the decreased activity and detection during times of increased precipitation might be due to changes in small mammal abundance. Small mammals might have a strong negative association with the turbine area, due to increased noise or vibrations, and thus during rainfall events mesocarnivores might forage in areas of higher small mammal density (Rabin et al. 2006). Contrary to this hypothesis, no differences in small mammals have been observed at turbines (De Lucas et al. 2005; Rabin et al. 2006). Although, small mammal responses to turbines remains poorly understood, and needs greater attention.

Vulpes velox had a higher probability of detection at roadway locations than field locations, (Fig. 8) while *C. latrans* showed no significant differences between roadway and field locations (Table 4). While literature sources suggest roadways are used for movement of mammalian mesocarnivores, the relationship has not been explored across ecosystems (Forman and Alexander 1998; Helldin et al. 2012; James and Stuart-Smith 2000). Most roadway use studies have been performed in areas where the surrounding landscape hinders movement. The smaller *V. velox* might have movement impeded by crops whereas *C. latrans* are large enough that they might not be hindered by similar vegetation. However, recent studies have suggested the use of roadways by carnivores is not a ubiquitous pattern among species and individuals; rather, that roadway use is dependent on variables such as age, sex, social position, and previous experiences (Larrueca et al. 2007; Sequin et al. 2003). Probably the modification and addition of roadways at wind facilities only affects mesocarnivores on a case by case basis and no catch-all management or siting guidelines will predict mesocarnivore response.

The treatment (control and turbine areas) affected mesocarnivore occupancy, with *C. latrans* having a higher probability of occupying the control area and *V. velox* having a higher probability of occupying the turbine area. While the top species co-occurrence model suggested *V. velox* had a higher probability of occupancy in the control area when *C. latrans* was present and detected, this referred to a very small portion of the overall detection data. Therefore models that described the greater portion of the data were chosen over those which fit a small subset of the data to more accurately describe the overall patterns of occupancy. Literature examples of *C. latrans* preying upon or displacing *V. velox* (Bekoff 1977; Egoscue 1979; Jackson and Choate 2000; Matlack et al. 2000), as well as the reciprocal nature of the initial modelable detection data (Table 2) prompted the examination of antagonizing species interactions on the occupancy patterns. Antagonizing interactions were apparent but occurred at a finer scale than occupancy, and were incorporated into the estimates of probability of detection. A study design that includes a larger wind facility and entire home ranges of mesocarnivores should show antagonistic interactions impacting both detection and occupancy.

The evidence for antagonistic interactions between *C. latrans* and *V. velox* came from probabilities of detection. The species co-occurrence models ranked formulas with *V. velox* detection conditional on both the presence and detection of *C. latrans* as being better supported than *V. velox* detection unconditional of *C. latrans* (Table 8). A clear example of the conditional nature of *V. velox* detections is the probability of detection for *V. velox* varying with mean precipitation (Fig. 7). The relationship between *V. velox* detection probability and mean precipitation was negative when *C. latrans* was not present or was present but not detected. However, when *C. latrans* was present and detected at a site the relationship between *V. velox* detection probability and precipitation became positive (Fig. 7). As *C. latrans* detection probability was impacted negatively by mean precipitation irrespective of *V. velox*, it suggests *V. velox* modified typical activity patterns to avoid *C. latrans*. This pattern could be viewed as competitive exclusion or predator avoidance on a temporal scale. Similar patterns were observed with detection probabilities at field locations (Fig. 8). When *C. latrans* was present and detected at a site, *V. velox* was detected almost exclusively at roadway locations. However, when *C. latrans* was no longer detected at a site, *V. velox* expanded its area of activity and had a higher probability of being detected at field locations. Another example of *V. velox* modifying behavior because of *C. latrans* could be seen with detection frequency over a 24 hour span (Fig. 3). *Vulpes velox* at the turbine area had a larger range of diurnal activity in the absence of *C. latrans*. The detection frequencies of both mesocarnivore species decreased to zero from 1030 to 1300 regardless of antagonistic interactions, suggesting a fixed temporal limit of mesocarnivore activity during the midday.

As wind energy technology expands across the United States, it increasingly will impact wildlife. My study suggests wind turbines play a role in modifying the occupancy pattern of mammalian mesocarnivores, specifically *C. latrans* and *V. velox*. Although this study cannot make predictions for wind energy across the country, some general patterns were apparent and should be explored at additional sites. Though *C. latrans* seemed to avoid turbines, *V. velox* was associated with turbine areas. Roadway alterations should be minimized in future wind energy development as roadways impacted *V. velox* detection probabilities within my study and would probably impact other species at wind facilities with denser surrounding vegetation (Helldin et al. 2012). Human activity did not have a strong influence on the detection of mesocarnivores surrounding wind turbines. This suggests turbine operational hours could remain constant without significantly altering mesocarniovore occupancy. The changes of mesocarnivore occupancy and behavior as highlighted throughout this study potentially could have implications for community structure and processes. Therefore, I advocate that mesocarnivore species management be formally considered during the siting process for wind facilities.

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Table 1- Seasonal divisions designated in PRESENCE multi-season occupancy models, based on biological significance to mammalian mesocarnivores (Bekoff 1977; Egoscue 1979).

Season	Duration	Survey Periods
Pack coalescence	September-November	1-2 and 14
Reproduction	November - March	3-6
Dispersal	March - July	7-11
Summer	July – August	12-13

Table 2- Mammalian mesocarnivore detections at the turbine and control study areas in Wichita County, Kansas. Detections were split into total detections and modelable detections, representing the first detection during each study period per site.

	Total Detections			Modelable Detections		
Species	Control	Turbine	**Total**	Control	Turbine	**Total**
Canis latrans	91	35	**126**	42	22	**64**
Vulpes velox	27	79	**106**	11	40	**51**
Mephitis mephitis	14	11	**25**	7	10	**17**
Procyon lotor	5	5	**10**	5	4	**9**
Taxidea taxus	4	2	**6**	4	2	**6**
Mustela frenata	2	0	**2**	1	0	**1**
Felis domesticus	0	1	**1**	0	1	**1**
Total	**143**	**133**	**276**	**70**	**79**	**149**

Table 3- Full set of seasonal occupancy model candidates for *Canis latrans* showing the difference in Akaike's Information Criterion (AIC) relative to the best model (ΔAIC), relative support for each model or AIC weight (*w*), the number of parameters (*K*), and -2 times the logarithm of the likelihood. Models show probability of occupancy (ψ), probability of colonization (γ), probability of extinction (ε), and probability of detection (p). Probabilities were either held constant (.) or were impacted by covariates. Covariates varied with season (s) or varied with survey (t). The top model suggested seasonal occupancy with colonization and detection held constant representing populations in a non-Markovian equilibrium.

Model	ΔAIC	*w*	*K*	-2*log(*L*)
ψ(.),γ(.),p(.)	0	0.8646	3	239.72
ψ(.),γ(.),p(s)	6.62	0.0316	7	238.34
ψ(.),γ(t),ε=1-γ,p(s)	6.88	0.0277	10	232.6
ψ(.),γ(t),p(s)	7.11	0.0247	10	232.83
ψ(.),γ(.),ε=1-γ,p(s)	7.66	0.0188	7	239.38
ψ,γ(.),ε(.),p(s)	8.18	0.0145	8	237.9
ψ(.),γ(.),p(t)	8.83	0.0105	16	222.55
ψ,γ(.),ε(.),p(t)	10.51	0.0045	17	222.23
ψ,γ(s),ε(t),p(s)	11.21	0.0032	14	228.93

Table 4- Full set of multi-season occupancy model candidates for *Canis latrans* showing the difference in Akaike's Information Criterion (AIC) relative to the best model (ΔAIC), relative support for each model or AIC weight (*w*), the number of parameters (*K*), and -2 times the logarithm of the likelihood. Models show probability of occupancy (ψ), probability of colonization (γ), probability of extinction (ε), and probability of detection (p). Probabilities were either held constant (.) or were impacted by covariates. Covariates varied between control and turbine areas (control), mean precipitation (precip), distance to nearest building (build), roadway location (road), field location (field), mean temperature (temp), agriculture and CRP land use (ag), and human activity index (traffic). The top model shows probability of occupancy varying between control and turbine areas, colonization as a constant, and the probability of detection varying with mean precipitation.

Model	ΔAIC	*w*	*K*	-2*log(*L*)
ψ(control),γ(.),p(precip)	0	0.1979	5	231.03
ψ(control),γ(.),p(precip+build)	0.6	0.1466	6	229.63
ψ(control),γ(.),p(precip+road)	1.28	0.1043	6	230.31
ψ(control),γ(.),p(.)	1.67	0.0859	4	234.7
ψ(control),γ(.),p(precip+temp)	2	0.0728	6	231.03
ψ(control),γ(.),p(precip+build+road)	2.06	0.0706	7	229.09
ψ(control),γ(.),p(build)	2.63	0.0531	5	233.66
ψ(control),γ(ag),p(.)	2.84	0.0478	5	233.87
ψ(control),γ(.),p(temp)	2.94	0.0455	5	233.97
ψ(control),γ(.),p(road)	3.1	0.042	5	234.13
ψ(control),γ(.),p(field)	3.13	0.0414	5	234.16
ψ(control),γ(.),p(traffic)	3.57	0.0332	5	234.6
ψ(control),γ(.),p(road+build)	4.22	0.024	6	233.25
ψ(.),γ(.),p(.)	4.69	0.019	3	239.72
ψ(control),γ(.),p(traffic+road)	5.04	0.0159	6	234.07

Table 5- Full set of seasonal occupancy model candidates for *Vulpes velox* showing the difference in Akaike's Information Criterion (AIC) relative to the best model (ΔAIC), relative support for each model or AIC weight (*w*), the number of parameters (*K*), and -2 times the logarithm of the likelihood. Models show probability of occupancy (ψ), probability of colonization (γ), probability of extinction (ε), and probability of detection (p). Probabilities were either held constant (.) or were impacted by covariates, varied between seasons (s). The top model suggested seasonal occupancy with colonization held constant and detection varying between seasons, representing populations in a non-Markovian equilibrium.

Model	ΔAIC	*w*	*K*	-2*log(*L*)
ψ(.),γ(.),p(s)	0	0.4928	8	213.4
ψ(.),γ(.),ε=1-γ,p(s)	1.47	0.2363	8	214.87
ψ,γ(.),ε(.),p(s)	2	0.1813	9	213.4
ψ(.),γ(.),p(.)	5.12	0.0381	3	228.52
ψ(.),γ(s),p(s)	5.16	0.0373	11	212.56
ψ(.),γ(s),ε=1-γ,p(s)	7.28	0.0129	11	214.68
ψ,γ(s),ε(s),p(s)	12.14	0.0011	15	211.54

Table 6- Full set of multi-season occupancy model candidates for *Vulpes velox* showing the difference in Akaike's Information Criterion relative to the best model (ΔAIC), relative support for each model or AIC weight (*w*), the number of parameters (*K*), and -2 times the logarithm of the likelihood. Models show probability of occupancy (ψ), probability of colonization (γ), probability of extinction (ε), and probability of detection (p). Probabilities were either held constant (.) or were impacted by covariates. Covariates varied between control and turbine areas (control), mean precipitation (precip), distance to nearest building (build), roadway location (road), field location (field), mean temperature (temp), agriculture and CRP land use (ag), and human activity index (traffic). The top model showed probability of occupancy varying between control and turbine areas, colonization as constant, and the probability of detection varying between seasons, field and roadway locations, and mean precipitation.

Model	ΔAIC	*w*	*K*	-2*log(*L*)
ψ(control),γ(.),p(s+field+precip)	0	0.123	11	182.47
ψ(control),γ(.),p(s+field)	0.63	0.0898	10	185.1
ψ(control),γ(.),p(s+field+precip+ag)	0.73	0.0854	12	181.2
ψ(control),γ(.),p(s+road)	1.04	0.0731	10	185.51
ψ(control),γ(.),p(s+field+precip+build)	1.14	0.0696	12	181.61
ψ(control),γ(.),p(s+field+precip+ag+build)	1.22	0.0668	13	179.69
ψ(control),γ(.),p(s+field+precip+traffic)	1.3	0.0642	12	181.77
ψ(control),γ(.),p(s+field+ag)	1.34	0.0629	11	183.81
ψ(control),γ(.),p(s+field+precip+temp)	1.75	0.0513	12	182.22
ψ(control),γ(.),p(s+field+build)	1.91	0.0473	11	184.38
ψ(control),γ(.),p(s+field+traffic)	1.96	0.0462	11	184.43
ψ(control),γ(.),p(s+field+temp)	1.98	0.0457	11	184.45
ψ(control),γ(.),p(s+field+precip+ag+traffic)	2.17	0.0416	13	180.64
ψ(control),γ(.),p(s+field+precip+ag+temp)	2.37	0.0376	13	180.84
ψ(control),γ(.),p(s+field+precip+ag+build+temp)	2.73	0.0314	14	179.2
ψ(control),γ(.),p(s+field+precip+ag+build+traffic)	2.93	0.0284	14	179.4
ψ(control),γ(.),p(s+field+traffic+build)	3.41	0.0224	12	183.88
ψ(control),γ(.),p(s+field+precip+ag+build+temp+traffic)	4.5	0.013	15	178.97
ψ(control),γ(.),p(s+traffic)	15.16	0.0001	10	199.63
ψ(control),γ(.),p(s)	15.26	0.0001	9	201.73
ψ(control),γ(.),p(s+ag)	15.47	0.0001	10	199.94
ψ(control),γ(.),p(s+build)	16.07	0	10	200.54
ψ(control),γ(.),p(s+precip)	16.29	0	10	200.76
ψ(control),γ(.),p(s+temp)	16.39	0	10	200.86
ψ(control),γ(ag),p(s)	17.19	0	10	201.66
ψ(.),γ(.),p(s)	24.93	0	8	213.4

Table 7- Full set of multi-season, species co-occurrence occupancy models explaining the interaction between dominant *Canis latrans* (species A) and *Vulpes velox* (species B) showing the difference in Akaike's Information Criterion relative to the best model (ΔAIC), relative support for each model or AIC weight (*w*), and the number of parameters (*K*). Occupancy models were either: (1) unconditional, where presence of *V. velox* was independent of presence of *C. latrans* (ψ^B); or (2) conditional, where presence of *V. velox* was dependent on the presence of *C. latrans* (ψ^{BA} and ψ^{Ba}). Occupancy covariates were either constant or a function of the control site (control). When *V. velox* occupancy was unconditional only one parameter was estimated. When *V. velox* occupancy was conditional, two parameters were estimated for the presence and absence of *C. latrans*. Three detection models where either: (1) *V. velox* detection probability was independent of *C. latrans* presence and detection (p^A,p^B); (2) *V. velox* detection probability was dependent on *C. latrans* presence but not detection (p^A,p^B,r^B); or (3) *V. velox* detection probability was dependent on both *C. latrans* presence and detection (p^A,p^B,r^{BA},r^{Ba}). Detection covariates were held constant using mean precipitation for *C. latrans* and both field location, and mean precipitation for *V. velox*. Seasonal changes of probability of colonization and extinction was held constant throughout.

Occupancy model	Detection model	ΔAIC	*w*	*K*
ψ^A,ψ^{BA}(control),ψ^{Ba}	p^A,p^B,r^{BA},r^{Ba}	0	0.6426	17
ψ^A(control),ψ^{BA}(control),ψ^{Ba}	p^A,p^B,r^{BA},r^{Ba}	3.74	0.099	18
ψ^A(control),ψ^{BA},ψ^{Ba}	p^A,p^B,r^{BA},r^{Ba}	3.77	0.0976	17
ψ^A(control),ψ^B(control)	p^A,p^B,r^{BA},r^{Ba}	5.42	0.0428	19
ψ^A(control),ψ^{BA}(control),ψ^{Ba}(control)	p^A,p^B,r^{BA},r^{Ba}	5.42	0.0428	19
ψ^A(control),ψ^{BA},ψ^{Ba}(control)	p^A,p^B,r^{BA},r^{Ba}	5.51	0.0409	18
ψ^A,ψ^B(control)	p^A,p^B,r^{BA},r^{Ba}	7.7	0.0137	18
$\psi^A,\psi^{BA},\psi^{Ba}$(control)	p^A,p^B,r^{BA},r^{Ba}	10.2	0.0039	17
ψ^A(control),ψ^{BA}(control),ψ^{Ba}	p^A,p^B,r^B	10.71	0.003	18
ψ^A(control),ψ^{BA},ψ^{Ba}	p^A,p^B,r^B	11.31	0.0022	17
ψ^A(control),ψ^B	p^A,p^B,r^{BA},r^{Ba}	11.9	0.0017	17
ψ^A(control),ψ^{BA}(control),ψ^{Ba}(control)	p^A,p^B,r^B	12.3	0.0014	19
ψ^A(control),ψ^B(control)	p^A,p^B,r^B	12.62	0.0012	19
ψ^A(control),ψ^{BA},ψ^{Ba}(control)	p^A,p^B,r^B	12.88	0.001	18
ψ^A(control),ψ^{BA},ψ^{Ba}	p^A,p^B	12.96	0.001	17
ψ^A(control),ψ^{BA}(control),ψ^{Ba}	p^A,p^B	12.98	0.001	18
ψ^A,ψ^{BA}(control),ψ^{Ba}	p^A,p^B,r^B	13.58	0.0007	17
ψ^A,ψ^B	p^A,p^B	13.97	0.0006	10
ψ^A,ψ^B(control)	p^A,p^B,r^B	14.07	0.0006	18
ψ^A(control),ψ^{BA}(control),ψ^{Ba}(control)	p^A,p^B	14.54	0.0004	19
ψ^A(control),ψ^{BA},ψ^{Ba}(control)	p^A,p^B	14.58	0.0004	18
ψ^A(control),ψ^B(control)	p^A,p^B	14.58	0.0004	19
$\psi^A,\psi^{BA},\psi^{Ba}$(control)	p^A,p^B,r^B	15.59	0.0003	17
$\psi^A,\psi^{BA},\psi^{Ba}$	p^A,p^B,r^{BA},r^{Ba}	15.98	0.0002	16

Table III1. Continued

Occupancy model	Detection model	ΔAIC	*w*	*K*
ψ^{A},ψ^{B}	$p^{A},p^{B},r^{BA},r^{Ba}$	15.99	0.0002	16
ψ^{A},ψ^{B}(control)	p^{A},p^{B}	17.03	0.0001	18
ψ^{A},ψ^{BA}(control),ψ^{Ba}	p^{A},p^{B}	17.27	0.0001	17
$\psi^{A},\psi^{BA},\psi^{Ba}$(control)	p^{A},p^{B}	18.44	0.0001	17
ψ^{A}(control),ψ^{B}	p^{A},p^{B},r^{B}	20.44	0	17
$\psi^{A},\psi^{BA},\psi^{Ba}$	p^{A},p^{B},r^{B}	21.67	0	16
ψ^{A},ψ^{B}	p^{A},p^{B},r^{B}	22.38	0	16
ψ^{A}(control),ψ^{B}	p^{A},p^{B}	23.58	0	17

Table 8- Relative support for different subsets of the species co-occurrence models where *Vulpes velox* was either conditional (C) or unconditional (U) of *Canis latrans* occupancy and *V. velox* detection probability was either conditional or unconditional on *C. latrans* occupancy and detection. Number of models (*N*) and the relative importance weight (w_+) or summed Akaike weights for all models sharing similar structure in the full set of candidate models reported within Table 7.

Effect of *Canis latrans* occupancy on *Vulpes velox* occupancy	Effect of *Canis latrans* occupancy on *Vulpes velox* detection	Effect of *Canis latrans* detection on *Vulpes velox* detection	*N*	w_+
C	C	C	7	0.927
U	C	C	4	0.0584
C	C	U	7	0.0086
C	U	U	7	0.003
U	C	U	4	0.0018

Fig. 1.- The study areas in Wichita County, Kansas containing the turbine area (Central Plains Wind Facility) to the north of state highway 96 (white line), and the control area ≥ 8 km to the south west.

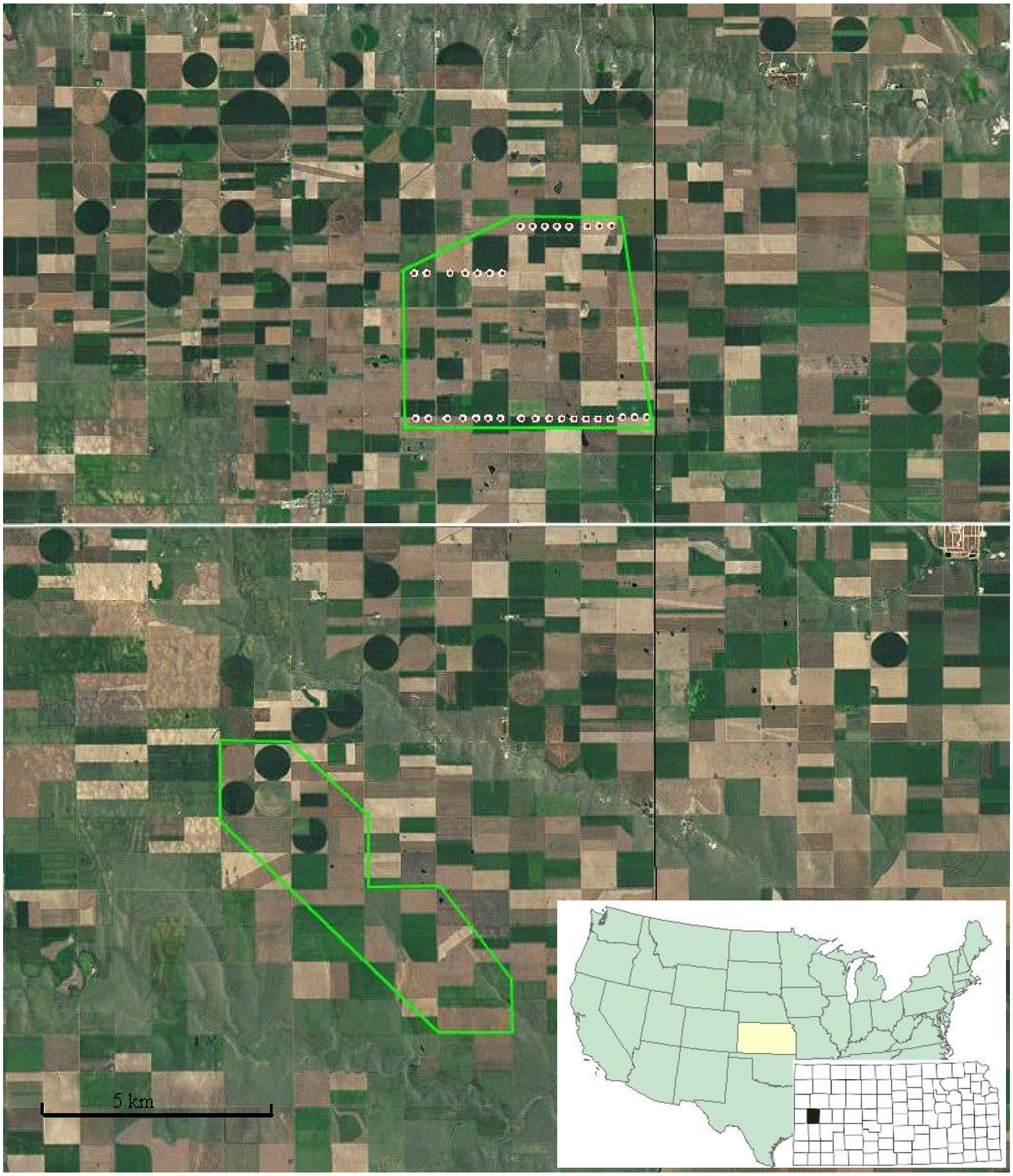


Fig. 2.- Modelable mesocarnivore detections for the turbine (dashed) and control (solid) study areas over the duration of the study. There was no significan difference between the two areas (*t* = -0.65, *d.f.* = 25.1, *P* = 0.52).

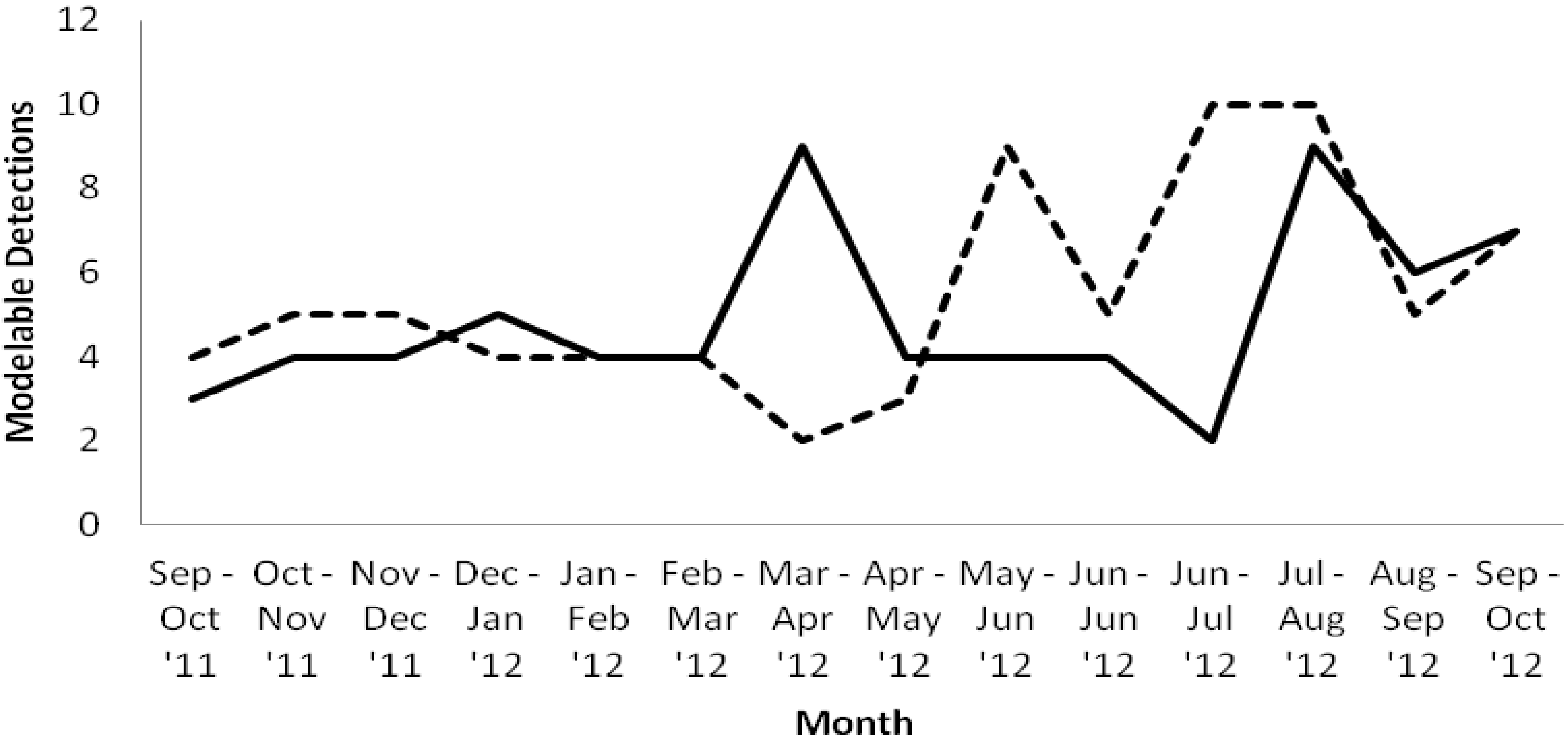


Fig. 3.- Frequency of detections for *Canis latrans* (solid) and *Vulpes velox* (dashed) at the control area (gray) and the turbine area (black). Detections reflect crepuscular activity of both species with some differences between study areas.

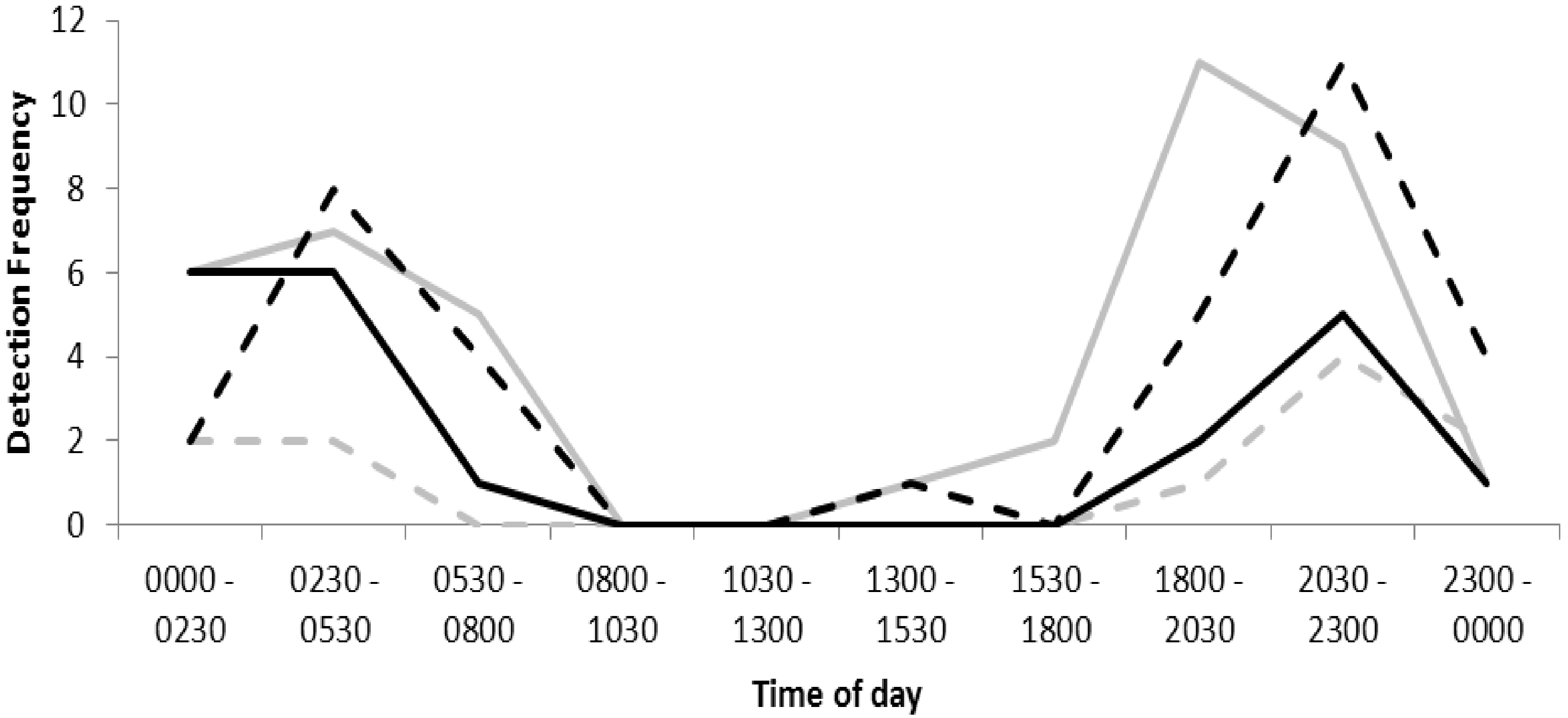


Fig. 4.- Mantel test showing no autocorrelation among modelable detections of (a) *Canis latrans* (*r* = 0.062, *d.f.* = 54, *P* = 0.04) and (b) *Vulpes velox* (*r* = -0.025, *d.f.* = 43, *P* = 0.70) at the spatial and temporal scales.

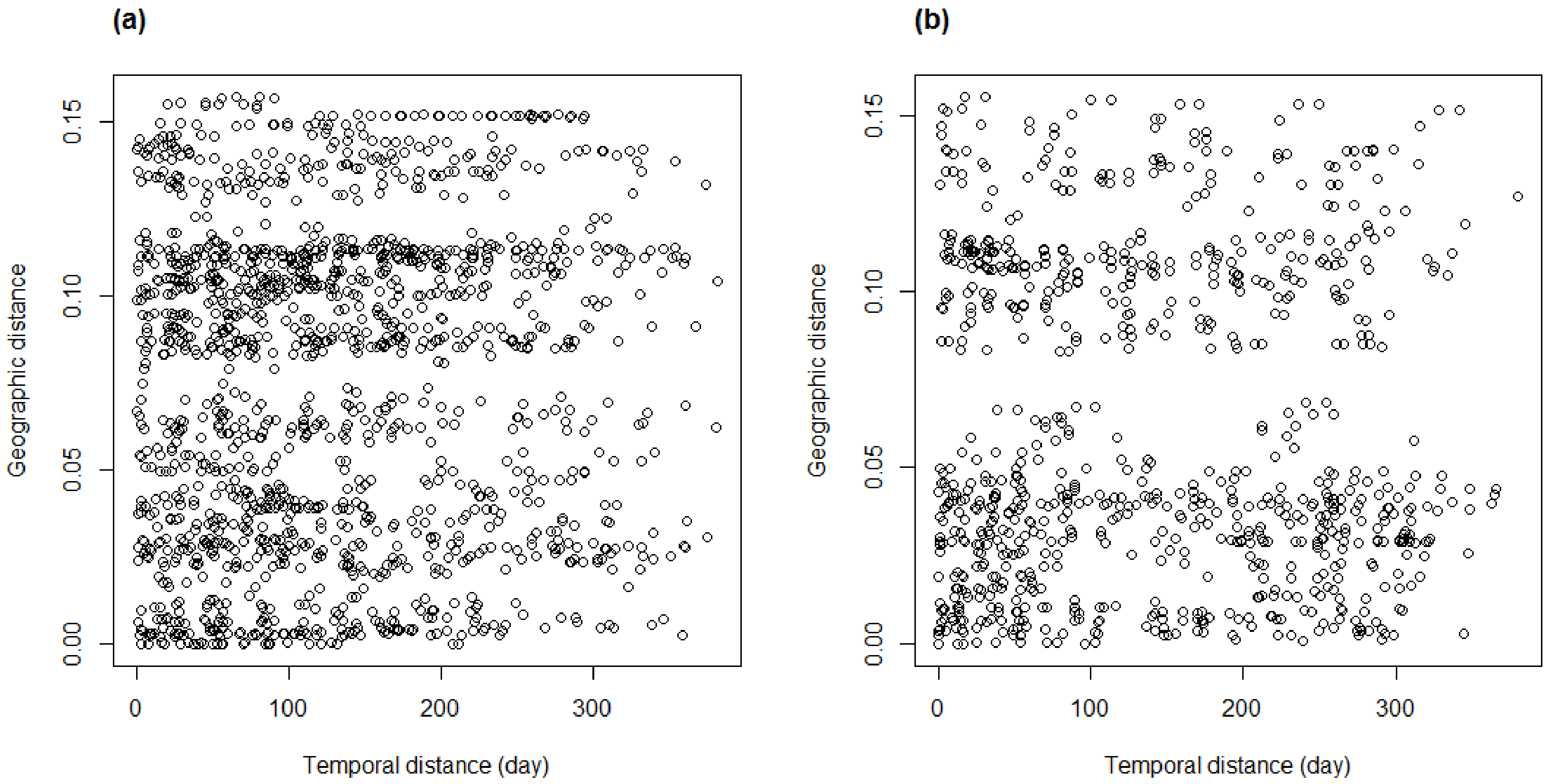


Fig. 5.- Human activity index measured by for the turbine (dashed) and control (solid) study areas over the duration of the study. Human activity differed significantly between areas (*t* = 5.72, *d.f.* = 131.9, $P < 0.001$).

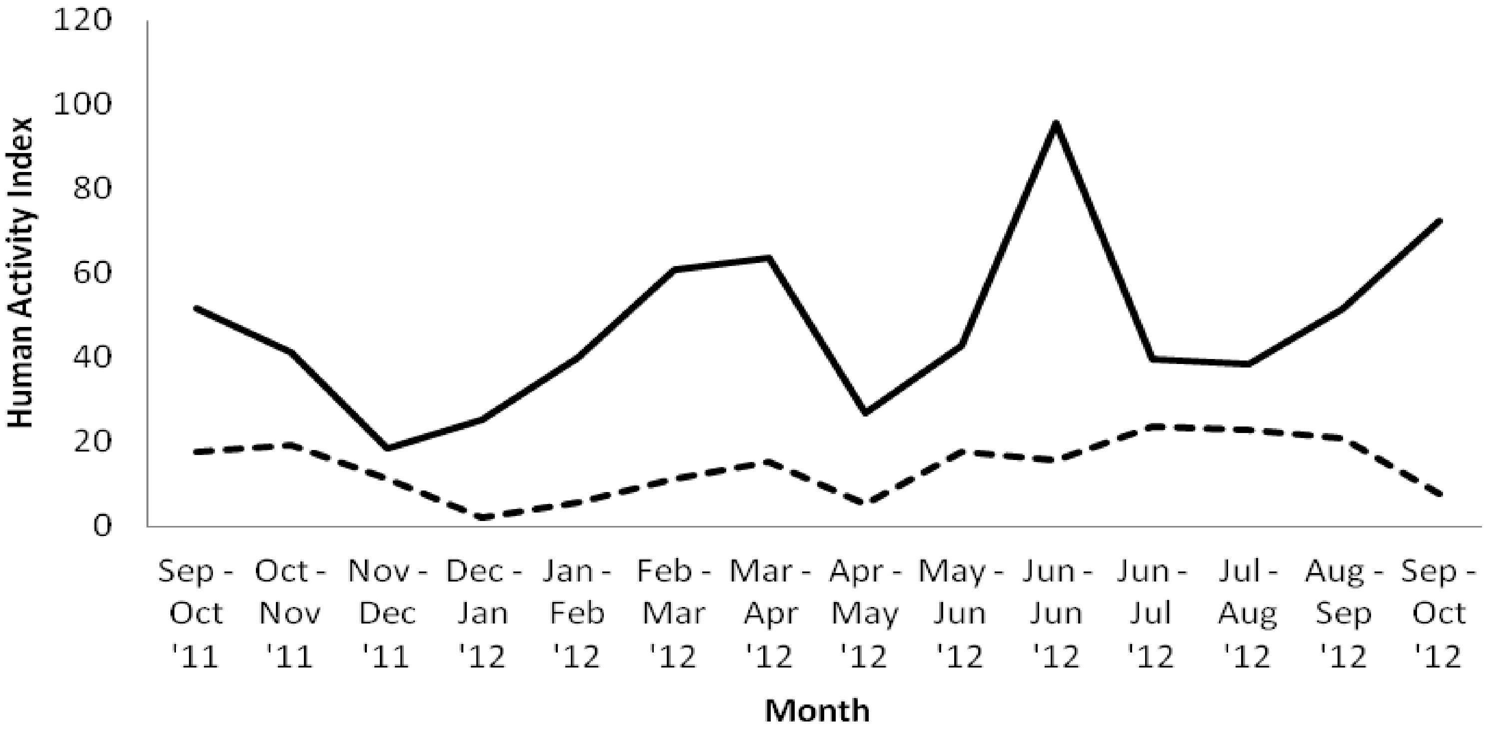


Fig. 6.- Probability of detection for *Canis latrans* as a function of mean precipitation (cm) from the second highest ranking species co-occurrence model. The thin dotted lines represent the 95% confidence intervals.

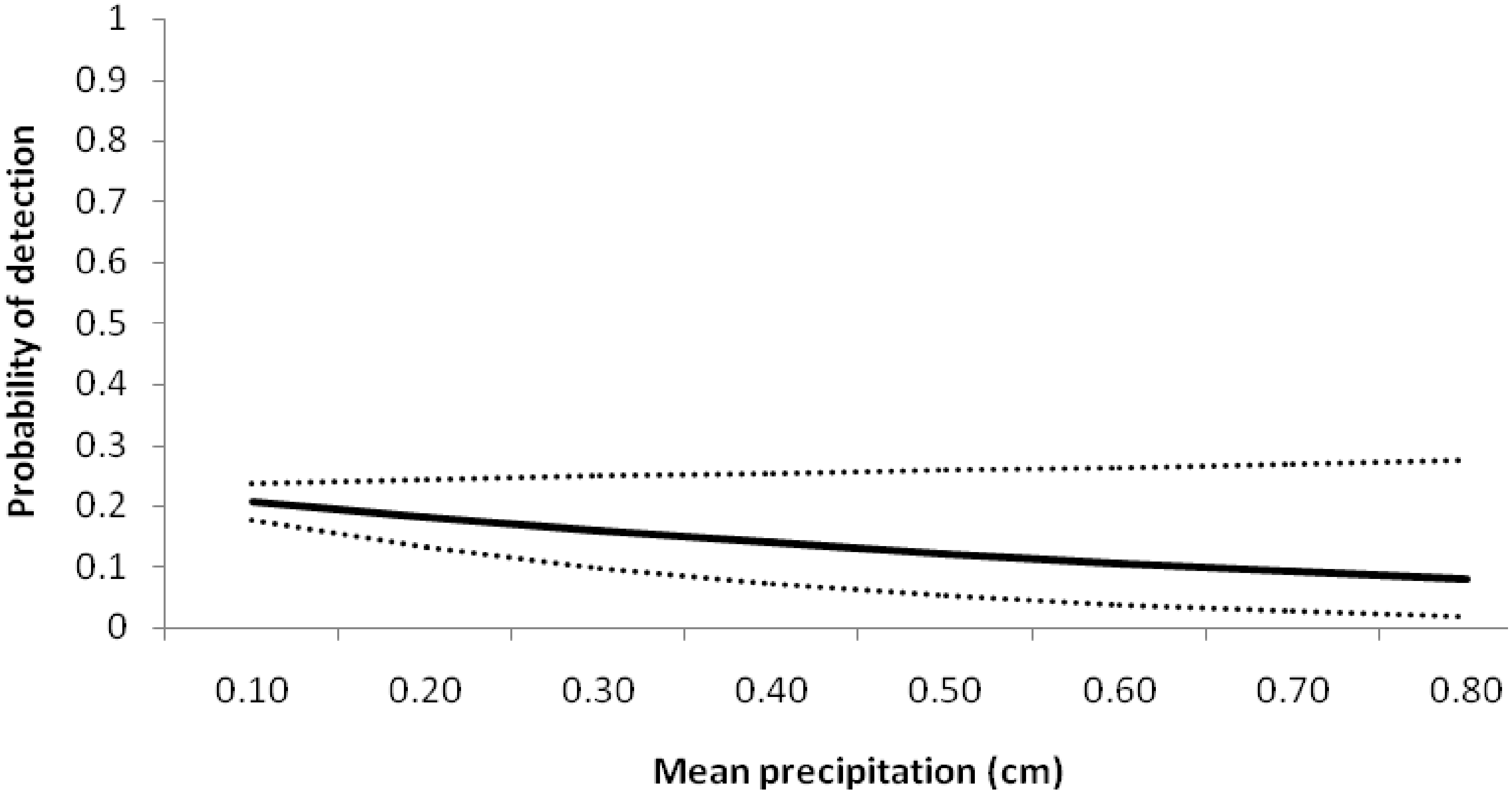


Fig. 7.- Probability of detection for *Vulpes velox* given the *Canis latrans* were present and detected (p^{BA}) and undetected (p^{Ba}) described as a function of mean precipitation (cm) from the second highest ranking species co-occurrence model. The thin dotted lines represent the 95% confidence intervals.

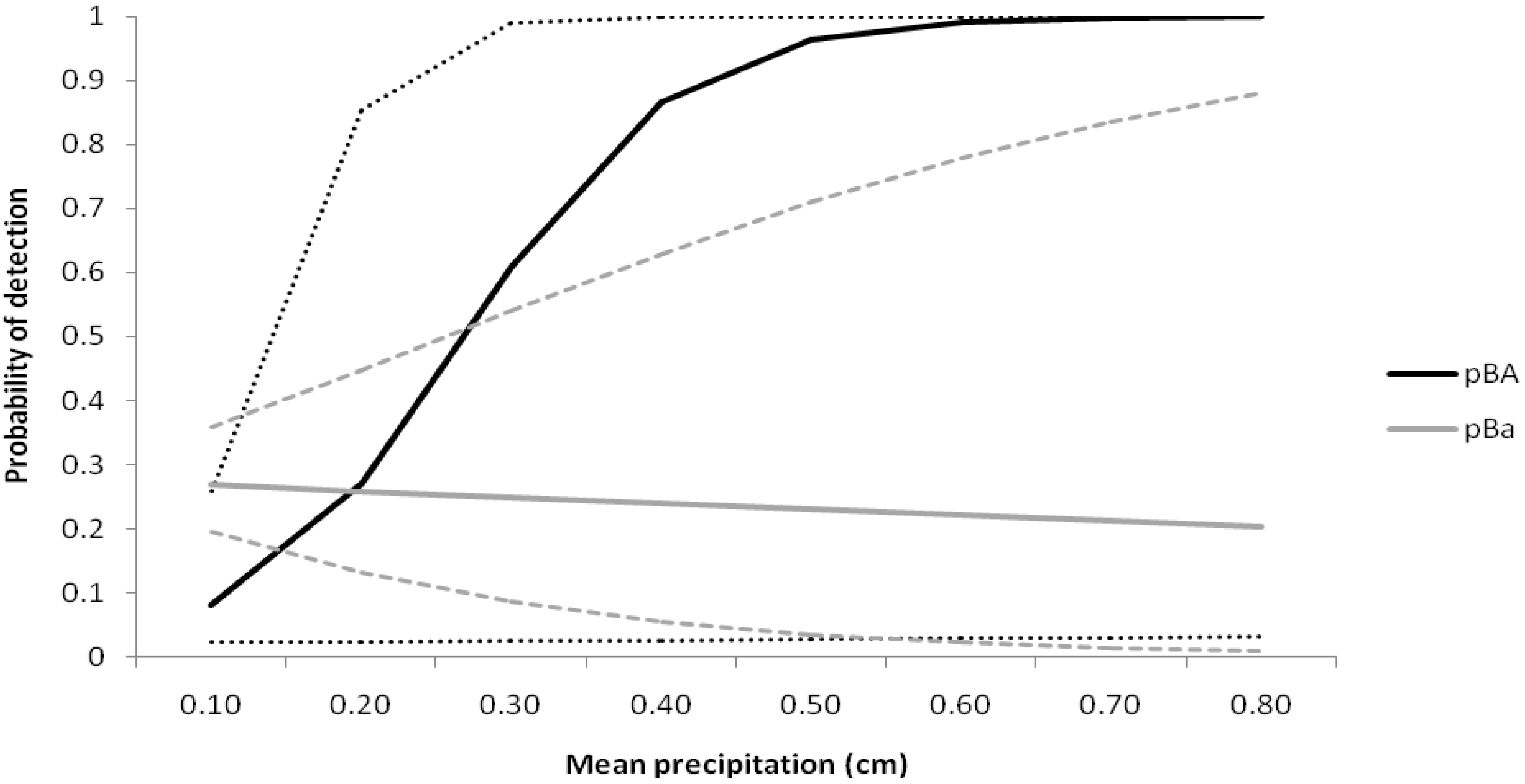
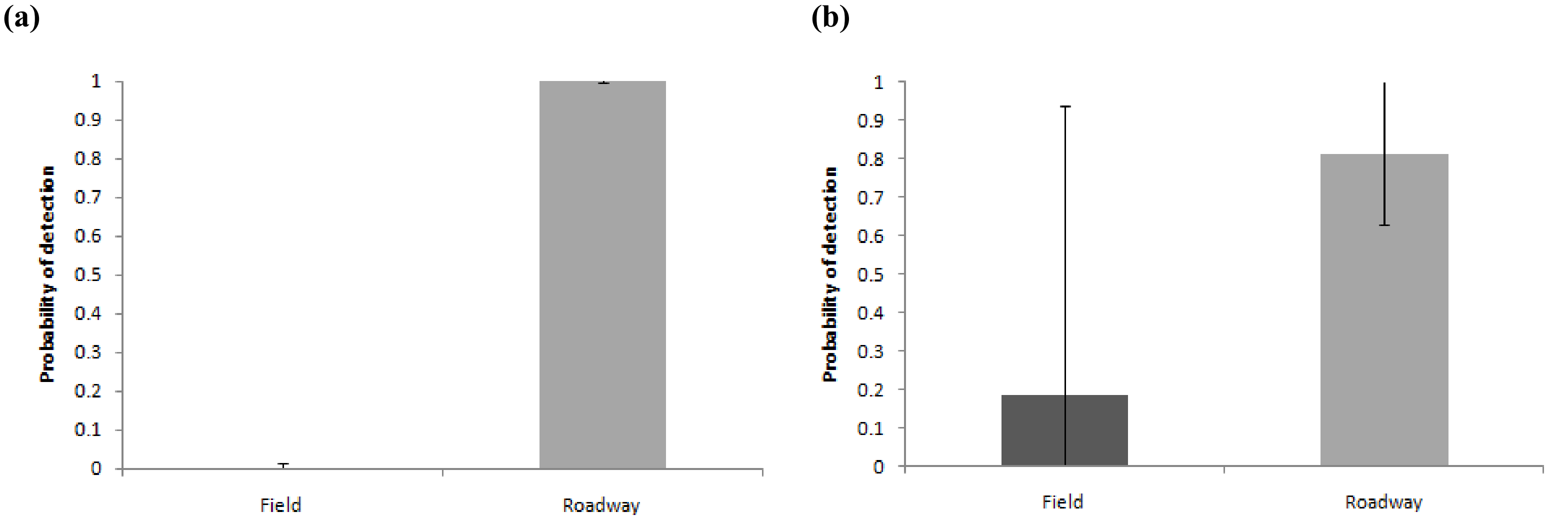


Fig. 8.- Probability of detection for *Vulpes velox* given the *Canis latrans* were present and detected (a) and undetected (b) described as a function of field locations from the second highest ranking species co-occurrence model.



APPENDIX I

Full suite of occupancy models run in PRESENCE corresponding to tables 3 through 7 written out in expanded form instead of standard phidot notation.

Table I3- Full set of seasonal occupancy model candidates for *Canis latrans* showing the difference in Akaike's Information Criterion (AIC) relative to the best model (ΔAIC), relative support for each model or AIC weight (*w*), the number of parameters (*K*), and -2 times the logarithm of the likelihood. The top model suggested seasonal occupancy with colonization and detection held constant representing populations in a non-Markovian equilibrium.

Model				ΔAIC	*w*	*K*	-2*log(*L*)
Probability of occupancy (ψ)	Probability of colinization (γ)	Probability of extinction (ε)	Probability of detection (*p*)				
Constant	Constant	NA	Constant	0	0.8646	3	239.72
Constant	Constant	Constant	Varied between season	6.62	0.0316	7	238.34
Constant	Varied between survey	1-γ	Varied between season	6.88	0.0277	10	232.60
Constant	Varied between survey	NA	Varied between season	7.11	0.0247	10	232.83
Constant	Constant	1-γ	Varied between season	7.66	0.0188	7	239.38
Constant	Constant	Constant	Varied between season	8.18	0.0145	8	237.90
Constant	Constant	NA	Varied between survey	8.83	0.0105	16	222.55
Constant	Constant	Constant	Varied between survey	10.51	0.0045	17	222.23
Constant	Varied between season	Varied between survey	Varied between season	11.21	0.0032	14	228.93

Table I4- Full set of multi-season occupancy model candidates for *Canis latrans* showing the difference in Akaike's Information Criterion (AIC) relative to the best model (ΔAIC), relative support for each model or AIC weight (*w*), the number of parameters (*K*), and -2 times the logarithm of the likelihood. The top model shows probability of occupancy varying between control and turbine areas, colonization as a constant, and the probability of detection varying with mean precipitation.

Model			ΔAIC	*w*	*K*	-2*log(*L*)
Probability of occupancy (ψ)	Probability of colonization (γ)	Probability of detection (*p*)				
Varied between area	Constant	Mean precipitation	0	0.1979	5	231.03
Varied between area	Constant	Mean precipitation + Distance to nearest building	0.6	0.1466	6	229.63
Varied between area	Constant	Mean precipitation + Varied between location	1.28	0.1043	6	230.31
Varied between area	Constant	Constant	1.67	0.0859	4	234.7
Varied between area	Constant	Mean precipitation + Mean temperature	2	0.0728	6	231.03
Varied between area	Constant	Mean precipitation + Distance to nearest building + Varied between location	2.06	0.0706	7	229.09
Varied between area	Constant	Distance to nearest building	2.63	0.0531	5	233.66
Varied between area	Varied between land use	Constant	2.84	0.0478	5	233.87
Varied between area	Constant	Mean temperature	2.94	0.0455	5	233.97
Varied between area	Constant	Varied between location	3.1	0.042	5	234.13
Varied between area	Constant	Varied between location	3.13	0.0414	5	234.16
Varied between area	Constant	Human activity index	3.57	0.0332	5	234.6
Varied between area	Constant	Varied between location + Distance to nearest building	4.22	0.024	6	233.25
Constant	Constant	Constant	4.69	0.019	3	239.72
Varied between area	Constant	Human activity index + Varied between location	5.04	0.0159	6	234.07

Table I5- Full set of seasonal occupancy model candidates for *Vulpes velox* showing the difference in Akaike's Information Criterion (AIC) relative to the best model (ΔAIC), relative support for each model or AIC weight (*w*), the number of parameters (*K*), and -2 times the logarithm of the likelihood. The top model suggested seasonal occupancy with colonization held constant and detection varying between seasons, representing populations in a non-Markovian equilibrium.

		Model		ΔAIC	*w*	*K*	-2*log(*L*)
Probability of occupancy (ψ)	Probability of colinization (γ)	Probability of extinction (ε)	Probability of detection (*p*)				
Constant	Constant	NA	Varied between season	0	0.4928	8	213.4
Constant	Constant	1-γ	Varied between season	1.47	0.2363	8	214.87
Constant	Constant	NA	Varied between season	2	0.1813	9	213.4
Constant	Constant	NA	Constant	5.12	0.0381	3	228.52
Constant	Varied between season	NA	Varied between season	5.16	0.0373	11	212.56
Constant	Varied between season	1-γ	Varied between season	7.28	0.0129	11	214.68
Constant	Varied between season	Varied between season	Varied between season	12.14	0.0011	15	211.54

Table I6- Full set of multi-season occupancy model candidates for *Vulpes velox* showing the difference in Akaike's Information Criterion relative to the best model (ΔAIC), relative support for each model or AIC weight (*w*), the number of parameters (*K*), and -2 times the logarithm of the likelihood. The top model showed probability of occupancy varying between control and turbine areas, colonization as constant, and the probability of detection varying between seasons, field and roadway locations, and mean precipitation.

Model			ΔAIC	*w*	*K*	-2*log(*L*)
Probability of occupancy (ψ)	Probability of colinization (γ)	Probability of detection (*p*)				
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation	0	0.123	11	182.47
Varied between area	Constant	Varied between season + Varied between location	0.63	0.0898	10	185.1
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Mean temperature	0.73	0.0854	12	181.2
Varied between area	Constant	Varied between season + Varied between location	1.04	0.0731	10	185.51
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Distance to nearest building	1.14	0.0696	12	181.61
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Varied between land use + Distance to nearest building	1.22	0.0668	13	179.69
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Human activity index	1.3	0.0642	12	181.77
Varied between area	Constant	Varied between season + Varied between location + Varied between land use	1.34	0.0629	11	183.81
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Mean temperature	1.75	0.0513	12	182.22
Varied between area	Constant	Varied between season + Varied between location + Distance to nearest building	1.91	0.0473	11	184.38

Table I6- Continued.

Model			ΔAIC	*w*	*K*	-2*log(*L*)
Probability of occupancy (ψ)	Probability of colinization (γ)	Probability of detection (*p*)				
Varied between area	Constant	Varied between season + Varied between location + Human activity index	1.96	0.0462	11	184.43
Varied between area	Constant	Varied between season + Varied between location + Mean temperature	1.98	0.0457	11	184.45
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Varied between land use + Human activity index	2.17	0.0416	13	180.64
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Varied between land use + Mean temperature	2.37	0.0376	13	180.84
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Varied between land use + Distance to nearest building + Mean temperature	2.73	0.0314	14	179.2
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Varied between land use + Distance to nearest building + Human activity index	2.93	0.0284	14	179.4
Varied between area	Constant	Varied between season + Varied between location + Human activity index + Distance to nearest building	3.41	0.0224	12	183.88
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Varied between land use + Distance to nearest building + Mean temperature + Human activity index	4.5	0.013	15	178.97
Varied between area	Constant	Varied between season + Human activity index	15.16	0.0001	10	199.63

Table I6 Continued.

Model			ΔAIC	*w*	*K*	-2*log(*L*)
Probability of occupancy (ψ)	Probability of occupancy (ψ)	Probability of occupancy (ψ)				
Varied between area	Constant	Varied between season	15.26	0.0001	9	201.73
Varied between area	Constant	Varied between season + Varied with land use	15.47	0.0001	10	199.94
Varied between area	Constant	Varied between season + Distance to nearest building	16.07	0	10	200.54
Varied between area	Constant	Varied between season + Mean precipitation	16.29	0	10	200.76
Varied between area	Constant	Varied between season + Mean temperature	16.39	0	10	200.86
Varied between area	Varied between land use	Varied between season	17.19	0	10	201.66
Constant	Constant	Varied between season	24.93	0	8	213.4
Varied between area	Constant	Varied between season + Varied between location + Distance to nearest building	1.91	0.0473	11	184.38
Varied between area	Constant	Varied between season + Varied between location + Human activity index	1.96	0.0462	11	184.43
Varied between area	Constant	Varied between season + Varied between location + Mean temperature	1.98	0.0457	11	184.45
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Varied between land use + Human activity index	2.17	0.0416	13	180.64

Table I6- Continued.

Model			ΔAIC	w	K	-2*log(L)
Probability of occupancy (ψ)	Probability of occupancy (ψ)	Probability of occupancy (ψ)				
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Varied between land use + Mean temperature	2.37	0.0376	13	180.84
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Varied between land use + Distance to nearest building + Mean temperature	2.73	0.0314	14	179.2
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Varied between land use + Distance to nearest building + Human activity index	2.93	0.0284	14	179.4
Varied between area	Constant	Varied between season + Varied between location + Human activity index + Distance to nearest building	3.41	0.0224	12	183.88
Varied between area	Constant	Varied between season + Varied between location + Mean precipitation + Varied between land use + Distance to nearest building + Mean temperature + Human activity index	4.5	0.013	15	178.97
Varied between area	Constant	Varied between season + Human activity index	15.16	0.0001	10	199.63
Varied between area	Constant	Varied between season	15.26	0.0001	9	201.73
Varied between area	Constant	Varied between season + Varied with land use	15.47	0.0001	10	199.94
Varied between area	Constant	Varied between season + Distance to nearest building	16.07	0	10	200.54
Varied between area	Constant	Varied between season + Mean precipitation	16.29	0	10	200.76

Table I6- Continued.

Model			ΔAIC	*w*	*K*	-2*log(*L*)
Probability of occupancy (ψ)	Probability of occupancy (ψ)	Probability of occupancy (ψ)				
Varied between area	Constant	Varied between season + Mean temperature	16.39	0	10	200.86
Varied between area	Varied between land use	Varied between season	17.19	0	10	201.66
Constant	Constant	Varied between season	24.93	0	8	213.4

Table I7- Full set of multi-season, species co-occurrence occupancy models explaining the interaction between dominant *Canis latrans* (species A) and *Vulpes velox* (species B) showing the difference in Akaike's Information Criterion relative to the best model (ΔAIC), relative support for each model or AIC weight (*w*), and the number of parameters (*K*). Occupancy models were either: (1) unconditional, where presence of *V. velox* was independent of presence of *C. latrans* (ψ^{B}); or (2) conditional, where presence of *V. velox* was dependent on the presence of *C. latrans* (ψ^{BA} and ψ^{Ba}). When *V. velox* occupancy was unconditional only one parameter was estimated. When *V. velox* occupancy was conditional, two parameters were estimated for the presence and absence of *C. latrans*. Three detection models where either: (1) *V. velox* detection probability was independent of *C. latrans* presence and detection (p^{A},p^{B}); (2) *V. velox* detection probability was dependent on *C. latrans* presence but not detection (p^{A},p^{B},r^{B}); or (3) *V. velox* detection probability was dependent on both *C. latrans* presence and detection (p^{A},p^{B},r^{BA},r^{Ba}). Seasonal changes of probability of colonization and extinction was held constant throughout.

Occupancy model				
Vulpes velox presence compared to *Canis latrans*	Probability of occupancy for *Canis latrans* (ψA)	Probability of occupancy for *Vulpes velox* (ψB)	Probability of occupancy for *Vulpes velox* when *Canis latrans* is present (ψBA)	Probability of occupancy for Vulpes velox when Canis latrans is absent (ψBa)
Conditional	Constant	NA	Varied between area	Constant
Conditional	Varied between area	NA	Varied between area	Constant
Conditional	Varied between area	NA	Constant	Constant
Unconditional	Varied between area	Constant	NA	NA
Conditional	Varied between area	NA	Varied between area	Varied between area

Table I7- Continued.

		Detection model				
Vulpes velox detection compared to *Canis latrans*		Probability of detection for *Canis latrans* given that *Vulpes velox* is absent (pA)	Probability of detection for *Vulpes velox* given that *Canis latrans* is absent (pB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present (rB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present and detected (rBA)	Probability of detection for Vulpes velox given Canis latrans is present and undetected (rBa)
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	NA	Mean precipitation + Varied between location	Mean precipitation + Varied between location
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	NA	Mean precipitation + Varied between location	Mean precipitation + Varied between location
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	NA	Mean precipitation + Varied between location	Mean precipitation + Varied between location
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	NA	Mean precipitation + Varied between location	Mean precipitation + Varied between location
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	NA	Mean precipitation + Varied between location	Mean precipitation + Varied between location

Table I7- Continued.

ΔAIC	*w*	*K*
0	0.6426	17
3.74	0.099	18
3.77	0.0976	17
5.42	0.0428	19
5.42	0.0428	19

Table I7- Continued.

Occupancy model				
Vulpes velox presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*
Conditional	Varied between area	NA	Constant	Varied between area
Unconditional	Constant	Varied between area	NA	NA
Conditional	Constant	NA	Constant	Varied between area
Conditional	Varied between area	NA	Varied between area	Constant
Conditional	Varied between area	NA	Constant	Constant

Table I7- Continued.

		Detection model				
Vulpes velox detection compared to *Canis latrans*		Probability of detection for *Canis latrans* given that *Vulpes velox* is absent (pA)	Probability of detection for *Vulpes velox* given that *Canis latrans* is absent (pB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present (rB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present and detected (rBA)	Probability of detection for Vulpes velox given Canis latrans is present and undetected (rBa)
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	NA	Mean precipitation + Varied between location	Mean precipitation + Varied between location
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	NA	Mean precipitation + Varied between location	Mean precipitation + Varied between location
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	NA	Mean precipitation + Varied between location	Mean precipitation + Varied between location
Dependent	Presence	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	NA	NA
Dependent	Presence	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	NA	NA

Table I7- Continued.

ΔAIC	*w*	*K*
5.51	0.0409	18
7.7	0.0137	18
10.2	0.0039	17
10.71	0.003	18
11.31	0.0022	17

Table I7- Continued.

Occupancy model				
Vulpes velox presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*
Unconditional	Varied between area	Constant	NA	NA
Conditional	Varied between area	NA	Varied between area	Varied between area
Unconditional	Varied between area	Varied between area	NA	NA
Conditional	Varied between area	NA	Constant	Varied between area
Conditional	Varied between area	NA	Constant	Constant

Table I7- Continued.

Detection model						
Vulpes velox detection compared to *Canis latrans*		Probability of detection for *Canis latrans* given that *Vulpes velox* is absent (pA)	Probability of detection for *Vulpes velox* given that *Canis latrans* is absent (pB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present (rB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present and detected (rBA)	Probability of detection for Vulpes velox given Canis latrans is present and undetected (rBa)
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	NA	Mean precipitation + Varied between location	Mean precipitation + Varied between location
Dependent	Presence	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	NA	NA
Dependent	Presence	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	NA	NA
Dependent	Presence	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	NA	NA
Independent	NA	Mean precipitation	Mean precipitation + Varied between location	NA	NA	NA

Table I7- Continued.

ΔAIC	*w*	*K*
11.9	0.0017	17
12.3	0.0014	19
12.62	0.0012	19
12.88	0.001	18
12.96	0.001	17

Table I7- Continued.

Occupancy model				
Vulpes velox presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*
Conditional	Varied between area	NA	Constant	Constant
Conditional	Constant	NA	Varied between area	Constant
Unconditional	Constant	Constant	NA	NA
Unconditional	Constant	Varied between area	NA	NA
Conditional	Varied between area	NA	Varied between area	Varied between area

Table I7- Continued.

Vulpes velox detection compared to *Canis latrans*		Detection model Probability of detection for *Canis latrans* given that *Vulpes velox* is absent (pA)	Probability of detection for *Vulpes velox* given that *Canis latrans* is absent (pB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present (rB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present and detected (rBA)	Probability of detection for Vulpes velox given Canis latrans is present and undetected (rBa)
Independent	NA	Mean precipitation	Mean precipitation + Varied between location	NA	NA	NA
Dependent	Presence	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	NA	NA
Independent	NA	Mean precipitation	Mean precipitation + Varied between location	NA	NA	NA
Dependent	Presence	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	NA	NA
Independent	NA	Mean precipitation	Mean precipitation + Varied between location	NA	NA	NA

Table I7- Continued.

ΔAIC	*w*	*K*
12.98	0.001	18
13.58	0.0007	17
13.97	0.0006	10
14.07	0.0006	18
14.54	0.0004	19

Table I7- Continued.

Occupancy model				
Vulpes velox presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*
Conditional	Varied between area	NA	Constant	Varied between area
Unconditional	Varied between area	Varied between area	NA	NA
Conditional	Constant	NA	Constant	Varied between area
Conditional	Constant	NA	Constant	Constant
Unconditional	Constant	Constant	NA	NA

Table I7- Continued.

Detection model						
Vulpes velox detection compared to *Canis latrans*		Probability of detection for *Canis latrans* given that *Vulpes velox* is absent (pA)	Probability of detection for *Vulpes velox* given that *Canis latrans* is absent (pB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present (rB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present and detected (rBA)	Probability of detection for Vulpes velox given Canis latrans is present and undetected (rBa)
Independent	NA	Mean precipitation	Mean precipitation + Varied between location	NA	NA	NA
Independent	NA	Mean precipitation	Mean precipitation + Varied between location	NA	NA	NA
Dependent	Presence	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	NA	NA
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	Mean precipitation + Varied between location	Mean precipitation + Varied between location
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	Mean precipitation + Varied between location	Mean precipitation + Varied between location

Table I7- Continued.

ΔAIC	*w*	*K*
14.58	0.0004	18
14.58	0.0004	19
15.59	0.0003	17
15.98	0.0002	16
15.99	0.0002	16

Table I7- Continued.

Occupancy model				
Vulpes velox presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*
Unconditional	Constant	Varied between area	NA	NA
Unconditional	Constant	NA	Varied between area	Constant
Conditional	Constant	NA	Constant	Varied between area
Unconditional	Varied between area	Constant	NA	NA
Conditional	Constant	NA	Constant	Constant

Table I7- Continued.

Detection model						
Vulpes velox detection compared to *Canis latrans*		Probability of detection for *Canis latrans* given that *Vulpes velox* is absent (pA)	Probability of detection for *Vulpes velox* given that *Canis latrans* is absent (pB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present (rB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present and detected (rBA)	Probability of detection for Vulpes velox given Canis latrans is present and undetected (rBa)
Independent	NA	Mean precipitation	Mean precipitation + Varied between location	NA	NA	NA
Independent	NA	Mean precipitation	Mean precipitation + Varied between location	NA	NA	NA
Independent	NA	Mean precipitation	Mean precipitation + Varied between location	NA	NA	NA
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	NA	NA
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	NA	NA

Table I7- Continued.

ΔAIC	*w*	*K*
17.03	0.0001	18
17.27	0.0001	17
18.44	0.0001	17
20.44	0	17
21.67	0	16

Table I7- Continued.

Occupancy model				
Vulpes velox presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*	*Vulpes velox* presence compared to *Canis latrans*
Unconditional	Constant	Constant	NA	NA
Unconditional	Varied between area	Constant	NA	NA

Table I7- Continued.

		Detection model				
Vulpes velox detection compared to *Canis latrans*		Probability of detection for *Canis latrans* given that *Vulpes velox* is absent (pA)	Probability of detection for *Vulpes velox* given that *Canis latrans* is absent (pB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present (rB)	Probability of detection for *Vulpes velox* given *Canis latrans* is present and detected (rBA)	Probability of detection for Vulpes velox given Canis latrans is present and undetected (rBa)
Dependent	Presence and detection	Mean precipitation	Mean precipitation + Varied between location	Mean precipitation + Varied between location	NA	NA
Independent	NA	Mean precipitation	Mean precipitation + Varied between location	NA	NA	NA

Table I7- Continued.

ΔAIC	*w*	*K*
22.38	0	16
23.58	0	17